FULLSPECTRUM

SIXTH FRAMEWORK PROGRAM

Project no. SES6-CT-2003-502620

FULLSPECTRUM

A new PV wave making more efficient use of the solar spectrum

Instrument:	Integrated Project
Thematic Priority:	Sustainable development, global change and ecosystems
Sub-priority:	Sustainable energy systems

Publishable Executive Summary of Fullspectrum updated after the 5th period

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Project coordinator name: Prof. Antonio Luque López

Project coordinator organisation name:
Instituto de Energía Solar – Universidad Politécnica de Madrid (IES-UPM)

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Publishable executive summary: FULLSPECTRUM

A new PV wave making more efficient use of the solar spectrum

Sponsored by the European Commission: 6th Framework Program: SES6-CT-2003-502620

FULLSPECTRUM is a project sponsored by the European Commission whose primary objective is to make use of the FULL solar SPECTRUM to produce electricity. The necessity for this research is easily understood, for example, from the fact that present commercial solar cells used for terrestrial applications are based on single gap semiconductor solar cells. These cells can by no means make use of the energy of below bandgap energy photons since these simply cannot be absorbed by the material.

Partnership involves nineteen Research Centres and Institutions, namely:

–	IES-UPM	Instituto de Energía Solar - Universidad Politécnica de Madrid (Coordinator)	http://www.ies.upm.es
–	PSE	Projektgesellschaft Solare Energiesysteme GmbH	http://www.pse.de
–	FhG-ISE	Fraunhofer Institute for Solar Energy Systems	http://www.ise.fhg.de/III-V
–	IOFFE	Ioffe Physico-Technical Institute	http://www.ioffe.rssi.ru
–	CEA	CEA / LETI / DOPT	http://www-leti.cea.fr
–	AZUR	AZUR SPACE Solar Power GmbH	http://www.azurspace.com/
–	PUM	Philipps University of Marburg	http://www.ub.uni-marburg.de/english/welcome.html
–	PSI	Paul Scherrer Institute	http://www.psi.ch/index_e.shtml
–	UG	University of Glasgow	http://www.elec.gla.ac.uk/
–	CSIC	Instituto de Catálisis y Petroleoquímica. Consejo Superior de Investigaciones Científicas	http://www.icp.csic.es/index.en.html
–	ECN	Energy Research Centre of the Netherlands	http://www.ecn.nl/index.en.html
–	UU-Sch	University of Utrecht	http://www.uu.nl /uupublish/homeuu /homeenglish/1757main.html
–	ICSTM	Imperial College of Science, Medicine and Technology	http://www.ess.ph.ic.ac.uk/~q_pv/
–	FhG-IAP	Fraunhofer-Institut fuer Angewandte Polymerforschung	http://www.iap.fhg.de/
–	Solaronix	Solaronix	http://www.solaronix.com/
–	ISOFOTON	ISOFOTON S.A	http://www.isofoton.es/
–	INSPIRA	INSPIRA	http://www.inspira.es/
–	EC-DG JRC	Joint Researh Centre - Institute for Enviroment and Sustainability	http://ies.jrc.cec.eu.int/Units/re/
–	UCY	University of Cyprus	http://www.ucy.ac.cy

The project is coordinated by the Instituto de Energía Solar of the Universidad Politécnica de Madrid. Contact details are: *Prof. Dr. Antonio Luque*; *Instituto de Energía Solar*; *ETSI Telecomunicación, UPM*; *28040 Madrid, Spain*; *email:* luque@ies-def.upm.es *or Prof. Antonio Martí, same address,* amarti@etsit.upm.es. PSE assists the Coordinator in its tasks.

Research, technology, development and innovation within the project is structured along five Activities whose content and objectives are briefly described below:

– *Multijunction Activity*. Is led by the Fraunhofer Institute for Solar Energy Systems. IOFFE, AZUR, CEA, IES-UPM and PUM are partners of the Activity. It aims to progress as much as possible towards the 40% efficiency goal using multijunction solar cells (Fig.1). The highest efficiencies are achived by monolithical triple-junction solar cell fabricated at FhG-ISE. It was grown by Metal Organic Vapour Phase Epitaxy, with GaInAs, GaInP and Ge as base materials. The research of suitable solar cells characterised by a 1 eV bandgap, the modelling and characterisation of the cells and the development of suitable characterisation tools are also tasks being developed within the Activity.

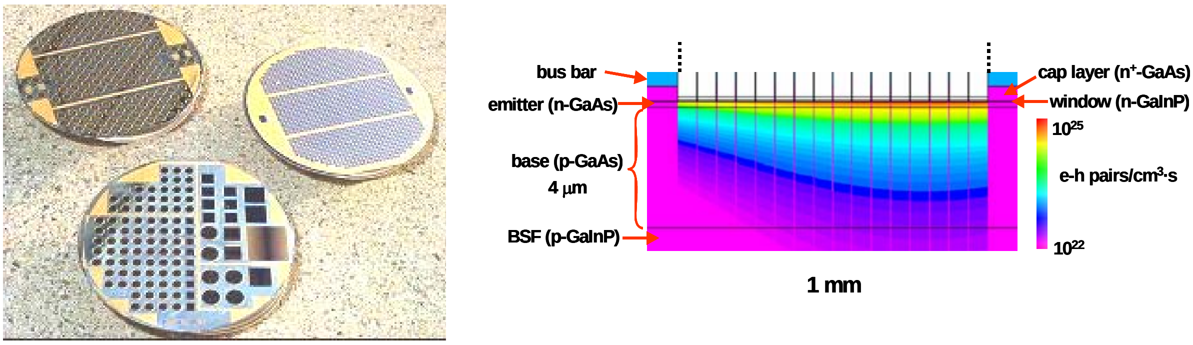


Fig. 1 Left: dual junction solar cells in their wafer. Right: computer simulation of the photogenerated current in a concentrator solar cell under non uniform illumination.

– *Thermophotovoltaics* (TPV). This activity aims to make a better use of the solar spectrum by using the sun to heat an appropriate emitter whose radiation is indeed used to illuminate solar cells. CEA and IOFFE are leaders of this Activity in which IES-UPM, FhG-ISE and PSI are also partners. Cells for TPV are mainly based on GaSb. The research within the activity involves the production of quality GaSb wafers, the manufacturing of the cells and their assembly into modules for their integration in the TPV systems, the research on efficient and adapted to the solar cell gaps emitters and the design of the system itself (Fig. 2).

– *Intermediate band cells.* This activity is led by IES-UPM. UG, ICP-CSIC and UCY join efforts in the development of the activity. The intermediate concept pursues the improvement in the utilization of the solar spectrum by using materials that inherently exhibit an intermediate band located within the otherwise conventional gap. Part of the activity is devoted to the early identification of these materials by means of quantum mechanical calculations (Fig. 3, left). The other part is devoted to experimentally prove the principles of operation of the intermediate band concept by artificially engineering the intermediate band using quantum dots (Fig 3, right). This also involves a strong activity in specific characterization and modelling.

– *Molecular based concepts.* It is led by ECN and ICSTM, FhG-IAP, Solaronix and UU-Sch participate in the activity. It aims to make a better use of the solar spectrum by exploiting molecules, QDs and QD aggregates with special optical properties. It mainly focuses in the development of flat concentrators, dye cells and up&down converters for solar cells. Flat concentrators collect the sunlight reemitting it at a given wavelength. Within the project, ways for obtaining more efficient concentrators are being investigated. In particular, concentrators also capable of emitting at more than one wavelength, suitable for use with multijunction cells are being researched. Figure 4(left) shows a flat concentrator prototype. Fig. 4(right) shows QDs synthesized in the search of materials susceptible of undergoing a two-photon-process.

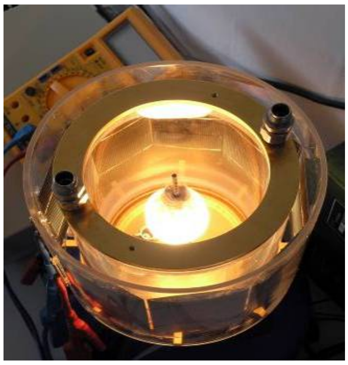
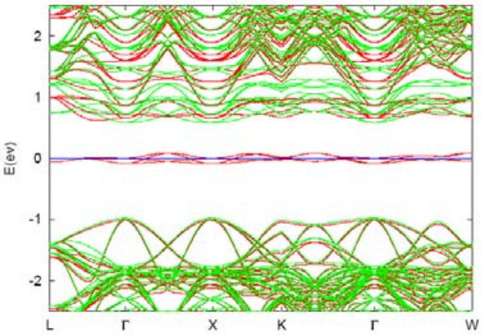


Fig. 2: Left, single GaSb CZ-crystal Ø 52-60 mm H 80 mm. Right, testing a TPV system consisting of an ytterbia oxide coated selective emitter, IR-filter and TPV cells array.



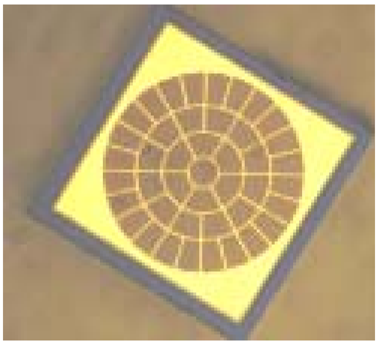
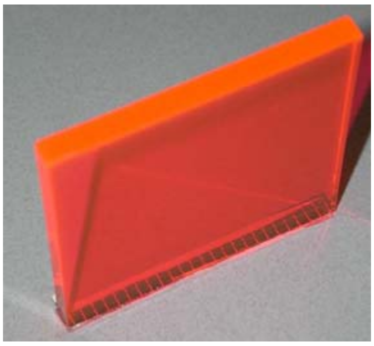


Fig. 3 Left, result of a quantum mechanical calculation in search of an intermediate band material. Right, Quantum dot intermediate band solar cell test sample.

– *Manufacturing*. This activity aims to implement at industrial level those concepts more promising for make a better use of the solar spectrum. It is led by ISOFOTON and EC-DG JRC, IES-UPM and INSPIRA are partners of the activity. Among these concepts, the one closest to commercialisation is the multijunction solar cell. Within the activity, compact concentrators have been developed, as the one shown in Fig. 5. Industrial prototypes consisting of over 200 MJCs with geometrical concentration of 1000 suns have been qualified. The development of the appropriate set-ups required to test the optical and overall efficiency of the single compact concentrator during development stages, self calibrating high precision trackers as well as the analysis of the longevity of the systems are also tasks being developed within this activity.



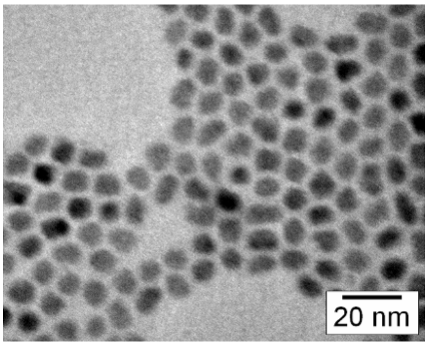
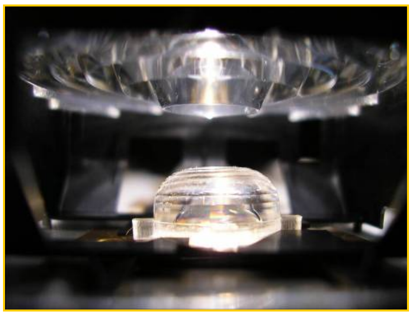


Fig. 4: Left, flat concentrator. At the bottom edge of the concentrator silicon cells are located. Right, PbSe quantum dots synthesized to form aggregates with CdSe QDs as basis for an up-converter material.



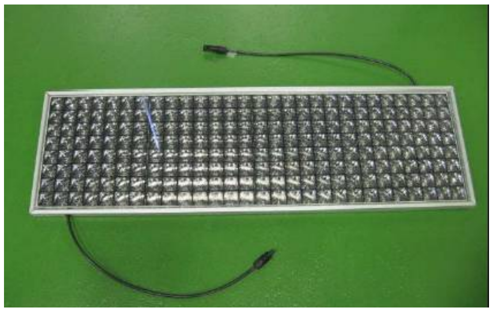


Fig. 5. (a) Unitary optical system of compact concentrator being developed within the activity “manufacturing” (b) Complete industrial prototype of HCPV module depeloped within the project

The advances produced within the project can be illustrated by saying that:

- Five world record efficiencies have been achieved: concentrator GaAs cell (28.6 % @293) by FhG-ISE, dual-junction cell (32.6 %@500-1000) by IES-UPM, triple-junction cell at high concentration (37.6 %@1700) by FhG-ISE, fuel-fired TPV system (3.96%) by PSI, luminescent solar concentrator (7.1%) by ECN.

- The principles of operation of the IBSC have been experimentally demonstrated using QD prototypes (IES-UPM, UG) and a bulk IB material based on a transition-metal-doped sulphide has been synthesized (CSIC,IES-UPM). The first hybrid solar/fuel-fired TPV system has been built.

- Industrial products developed: triple-junction cells with efficiencies ~35% (AZUR), compact high concetration modules (Isofotón), concentrator characterization tool for mass production (IES-UPM).

Some examples of publications generated during the Project:

– W.G.J.H.M. Van Sark, “*Enhancement of solar cell performance by employing planar spectral converters*”, Appl. Phys. Lett. **87** 151117 (2005).

– L. H. Slooff, E. E. Bende, A. R. Burgers, T. Budel, M. Praventtoni, R. P. Kenny, E. D. Dunlop, and A. Büchtemann, *"A luminescent solar concentrator with 7.1% power conversion efficiency"*; Physica Status Solidi-Rapid Research Letters pp. 1-4, 2008.

– J. Schöne, E. Spiecker, F. Dimroth, A. Bett, and W. Jäger, *"Misfit dislocation blocking by dilute nitride intermediate layers";* Applied Physics Letters, vol. 92, p. 081905, 2008.

– A. Luque, A. Martí, E. Antolín et al., “*Intermediate bands versus levels in non-radiative recombination*”, Physica B, **382**, 320–327 (2006).

– A. Martí, E. Antolín, C. Stanley et al, “*Production of Photocurrent due to Intermediate-to-Conduction-Band Transitions: A Demonstration of a Key Operating Principle of the Intermediate-Band Solar Cell*”, Phys. Rev. Lett. **97**, pp. 247701-4 (2006).

– P. Palacios, I. Aguilera, K. Sánchez, J. C. Conesa, and P. Wahnón, *"Transition Metal Substituted Indium Thiospinels: Towards an Ab Initio Understanding of the Intermediate Band Formation";* Phys. Rev. Lett, vol. 101, p. 046403, 2008.

– V.M.Andreev, A.S.Vlasov, V.P.Khvostikov, and al., *“Solar thermophotovoltaic converter with Fresnel lens and GaSb cells”*, Procs. of the IEEE 4th World Conference on Photovoltaic Energy Conversion Hawaii, May 2006.

– L.B.Karlina, A.S.Vlasov, M.M.Kulagina, and al., *“Thermophotovoltaic converters based on In0.53Ga0.47As/InP heterostuctures”*, Semiconductors, **40**, issue 3, pp. 351-355 (2206).

– V.Díaz, J.Alonso, J.L.Álvarez, and al., *“The Path for Industrial Scale Production of Very High Concentration PV Systems”*. 3rd International Conference on Solar Concentrators for the Generation of Electricity and Hydrogen. Scottdale, Arizona, May 2005.

– I. Luque-Heredia, R. Cervantes, G. Quéméré, *“A Sun Tracking Error Monitor for Photovoltaic Concentrators”*, Procs. of the 4th World Conference on Photovoltaic Energy Conversion, Hawaii 2006.

– F. Dimroth, C. Baur, A.W. Bett, and al., *“Junction Photovoltaic Cells for Space and Terrestrial Concentrator applications”* Proc. of 31 IEEE PVSC, USA, January 2005

– W. Guter , A.W. Bett, “*IV-Characterization of Tunnel Diodes and Multi-Junction Solar Cells*”, IEEE Trans. Elect. Dev., **53**, 9, 2216-2222, 2006.

– I. García, I. Rey-Stolle, C. Algora, K. Volz, and W. Stolz, "*Influence of GaInP ordering on the electronic quality of concentrator solar cells*"; Journal of Crystal Growth,vol.310, 23, pp.5209-5213, 2008.